



Spin Currents Encounter Friction *Spin Coulomb Drag Verified Experimentally*

An LBNL team led by Joe Orenstein, in collaboration with the group of David Awschalom at the University of California, Santa Barbara, has made the first observation of the friction encountered by a spinning electron as it attempts to propagate through a sea of other electrons spinning in the opposite direction. This effect, known as “spin-Coulomb drag,” has important implications for the growing field of spintronics, the study of devices based on electron spin.

Electronic devices, such as the millions of transistors in a modern integrated circuit, process information by controlling the flow of electrons. The basic element of digital technology, the logical one or zero, is encoded by the presence or absence of electronic charge at a defined position in the storage medium. However, manipulating the charge of the electron generates unwanted heat through Ohmic dissipation and has inherent time delays associated with the charging and discharging of capacitors.

In addition to its negative charge, an electron also carries a quantized unit of angular momentum known as “spin,” which can assume either of two directions, referred to as “up” and “down.” It has been predicted that

Non-volatile magnetic random access memory chips based on electron spin would eliminate the delay in computer start-up

devices based on an electron’s spin could be smaller, faster, and dissipate less heat than those based solely on charge. In fact, electron spin is already making its mark on the computer industry with the development of non-volatile magnetic random access memory chips, or MRAMs, implementation of which would, for example, eliminate the delay time in starting up a computer. However, full realization of the promise of spintronics requires a much better understanding of spin currents created by the motion of electrons through a semiconductor.

A pure spin current requires the counterpropagation of electrons with opposite spin, for example a flow of “up” electrons to the left and “down” electrons to the right. Before this LBNL work, it had been widely assumed that this counterflow would be impeded only by collisions between electrons and impurities, and not by collisions between the oppositely spinning electrons. This prejudice came from experience with charge currents, where it is known that the Ohmic resistance originates with impurity scattering, and not collisions between electrons.

The key to measuring the friction of counterpropagating spins is an experimental technique known as transient grating spectroscopy, which had been developed earlier by Orenstein to measure charge motion in superconductors (MSD Highlight 04-03). In transient grating experiments, two beams of laser light, polarized at 90-degrees with respect to each other, are superposed at the surface of a semiconductor. The superposition produces a periodic pattern of alternating left and right circular polarized light, creating alternating bands of spin up and spin down electrons at the surface. The rate at which these bands decay is a direct measure of the ability of electrons with opposing spins to flow past each other. The experiments revealed the existence of an unexpected frictional force, which was named “spin-Coulomb drag.”

The spin Coulomb drag effect is a consequence of the different effect of electron-electron collisions on charge and spin currents. Momentum is conserved in such collisions, and therefore the charge current is unaffected. However, momentum can flow from spin up to spin down electrons, and this creates the drag force unique to spin currents. Depending on the application, spin Coulomb drag could prove to be either an advantage or a disadvantage. Although the drag adds to the force required to drive a pure spin current, it will extend the lifetime of localized packets of polarized spin that could be used to store and transmit information. Continuing research will focus on manipulation of spin polarization and spin current through the use of electrical gating to modify spin-orbit interactions.

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C. P. Weber, N. Gedik, J. E. Moore, J. Orenstein, J. Stephens, and D. D. Awschalom, “Observation of spin Coulomb drag in a two-dimensional electron gas,” *Nature* **437**, 1330 (2005).

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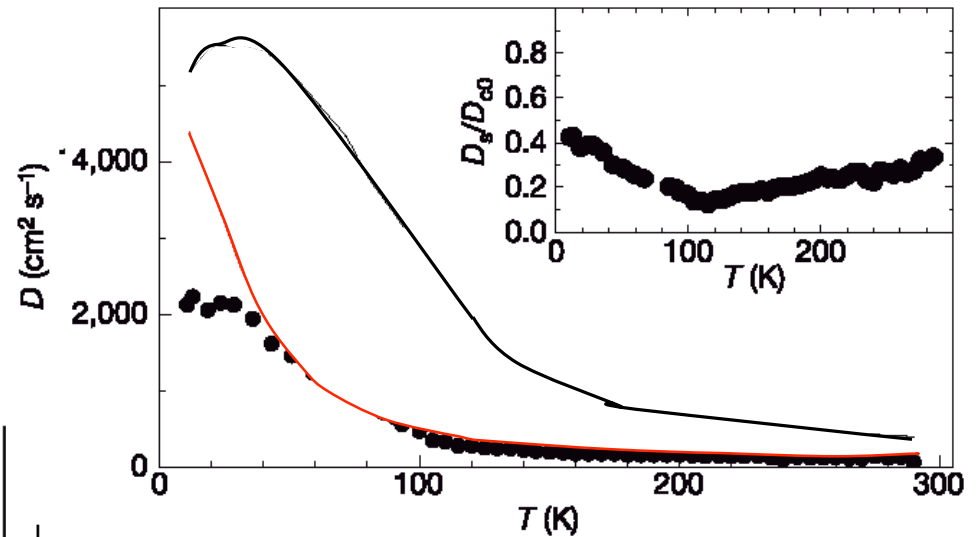
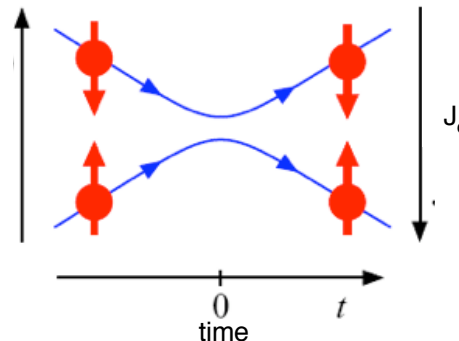


Charge and spin. In addition to its negative charge, an electron carries intrinsic angular momentum, "spin" resulting from its rotation. The up and down values of spin can be used to encode logical ones and zeros in a digital computer.

Collisions and spin current:

two colliding electrons in the 2-dimensional electron gas. Total momentum is conserved; thus total charge current is unchanged. However, total spin current flips sign; it is proportional to the **relative** momentum of the electrons.

Before the collision at $t=0$ the spin-up electron moves up while the spin-down electron moves down, creating an "up" net spin current. After the collision, the directions of spin-up and down electrons are reversed, so the net spin current is "down". This reversal, through many such collisions, gives rise to a frictional force (or spin-Coulomb drag) that inhibits the relative motion of electrons with opposite spin.



Measurements of spin Coulomb drag in the two-dimensional electron gas in a GaAs quantum well. The diffusion coefficients, D , were measured using a spin-sensitive transient grating approach which creates a non-equilibrium population of spin "up" and "down" electrons and monitors their motion as a function of time. The solid black line is the charge diffusion coefficient. Spin diffusion [experiment (circles) and theory (red line)] is slower; a result of spin-Coulomb drag. The inset shows the ratio of the two coefficients.